PHYSIOLOGICAL AND INFORMATION PROCESSING INDICES IN THE SELECTION OF STUDENTS FOR RIGOROUS EDUCATIONAL PROGRAMS

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THESIS

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ABSTRACT

Three groups of subjects were tested with serial reaction time tests of varying complexity and presentation rate. An ECG was collected from each subject throughout the test, and a measure of internal processing speed was defined using the ECG as input. It was found that there was an observable effect of the internal processing speed on the response rate of the subjects. An examination of relative scholastic achievement of the subjects showed that it was related to the change in the subject's performance as the complexity of the serial reaction time test was increased.

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I. INTRODUCTION

A. BACKGROUND

Sinus arrythmia is the lack of regularity in one's heart beat. An individual's heart is normally speeding and slowing about its mean rate. A cardiotachometer plot of this phenomena is somewhat sinusoidal in nature, indicating the fluctuations are controlled in some regular manner. The relationship between sinus arrythmia and mental load has been studied in greatest depth by J. W. H. Kalsbeek (1971), who demonstrated the effects of mental load both on sinus arrythmia and respiration. Dr. Kalsbeek used the number of times the heart rate deviated from its mean by three, six or nine beats per minute in either direction as a measure of irregularity, and then examined the behavior of this irregularity under varying conditions and types of mental load. From his studies he was able to order several nonhomogenous tasks by mental load, using sinus arrythmia suppression as a measure.

Later work by Hicks and Soliday (1972) utilized S/N, where "S refers to the sum of the positive time differences of consecutive inter-beat intervals" and "N refers to the number of waves", as a measure of sinus arrythmia. The subjects were tested with slightly different mental loadings than those used by Kalsbeek. The authors concluded that sinus arrythmia did reflect the mental load being

experienced, validating Kalsbeek's position in several points. It was specified that more work was necessary before sinus arrythmia could be used in practical applications.

B. PURPOSE

Further examination of sinus arrythmia was undertaken here with the intent of refining the techniques involved to the point where sinus arrythmia could be used as a predictor of individual scholastic performance. Selection of best qualified students for difficult programs has always been a concern of administrators. While it was not expected that a physical indicator could measure knowledge already amassed, it was felt that if candidates could be ranked on their ability to absorb new and difficult material, the problem of selection would be reduced in scope significantly. Advance preparation can be made for the type of test normally used for this purpose (soch as the Graduate Record Examination). The more information available concerning th test the better the subject can prepare, and consequently perform. If a physiological indicator could be used as a control while testing the subject over a range of mental loadings, a ranking between subjects could be achieved that would be relatively insensitive to knowledge, and difficult to outwit by prior preparation. This ranking would be useful only if it related to the desired measure (s) of performance. Since it had been demonstrated that sinus arrythmia was related to

mental load, its behavior under controlled increases in mental load was selected as the basis for study. A consistent relationship between a measure of sinus arrythmia and a scale of increasing mental load combined with a standard set of loadings would provide the desired rankings.

II. THE NATURE OF THE PROBLEM

Inherent in the study of a phenomena is the selection of an adequate model describing it. The human nervous system was modeled as a multi-processing, real time, time sharing system where the central coordination was performed during a cycle of fixed length (in decisions), but whose processing rate could be varied. The cycle was treated as being of arbitrary composition task-wise, with the restriction that selected functions had to be performed each cycle.

The use of a computer analogy is not new. Fitts and Posner (1967) described a system where a set of subroutines were controlled by an executive routine. An extension of this model leads to the one described above. Multi-processing is evidenced in several ways. Learned responses to complex situations, such as shifting gears in a motor vehicle, require such a diversity of processing, both input and output that it is difficult to envision them as purely sequential actions. Similarly, reflex responses, such as to pain, indicate that some responses occur without the conscious prior knowledge of the individual. Chapanis' (1969) description of the advantages of dichotic listening (different inputs to each ear) over binaural (identical inputs to both ears) supports the model. It appears that the brain can decide to ignore one ear, then process the information in the other with no loss of efficiency. This screening operation runs parallel to the actual information processing, but not on a conscious level.

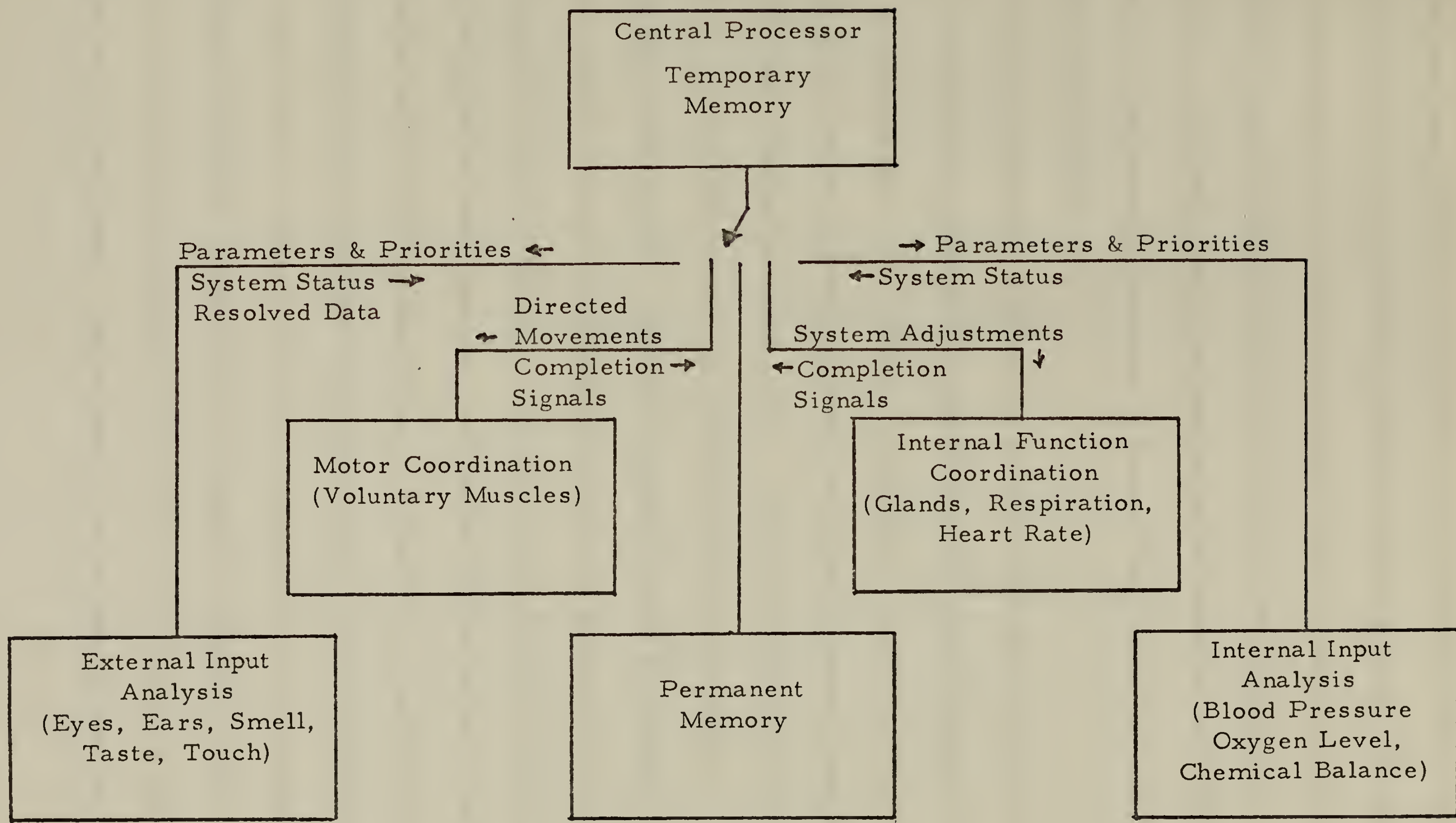

Figure 1. Model of Human Processing

The way people naturally circumvent the tendency to follow one train of thought at a time leads to the time sharing concept. Simultaneous conscious control of two unlearned actions is extremely difficult. Fitts and Posner's (1967) model of learning tends to confirm this, since the gradual reduction in conscious control required as a skill is learned can permit an increase in concurrent processing (such as talking while working).

Real time response to stimuli is required by several parts of the body. Heart rate, respiration, glandular action, pupil dialation, etc. must be continually kept in control. Respiration, in particular, is a complicated process requiring several real time decisions, such as when to start inhaling and when to stop. These decisions must be based on current information, and must be made with sufficient regularity that the oxygen content of the blood can be maintained within limits. Studies of pupil contraction with external processing overload are consistent with this concept. In cases where insufficient processing is relegated to body functions, noticeable failures occur. Brenner and Hothersall's (1972) studies of heart rate slowing found irregularities in breathing which could also be a failure of the system to provide real time respiration decisions. The brain is trained to vary respiration with the increased heart rate which accompanies physical work, but a decrease with its resulting slower blood flow would require a higher oxygen level in the blood. The necessary accompanying respiration

changes are not conditioned responses like those accompanying speeding of heart rate. Hicks and Soliday's discussion of the possible causes of sinus arrythmia - a balance between the sympathetic and para-sympathetic nervous system - would seem to explain much of the resurgence effect of sinus arrythmia. For instance, if sinus arrythmia is a balance between the brain attempting to balance blood flow to respiration to yield a constant oxygen content in the blood, and blood flow to the body to produce a constant availability of oxygen (and energy) to the cells, then a reduction in the processing involved in this balance would create irregularities throughout the body. Accumulation of these irregularities would then require a return to balance to prevent permanent damage.

An important element of the model is the mechanism by which coordination is affected. It was postulated that there is a control cycle of fixed length (in decisions). The real time section of the hypothesis requires that decisions affecting certain functions be on a regular basis, so these decisions were treated as delimiters of the cycle. The nature of the remaining decisions was treated as being arbitrary, such as either input analysis, output direction, or internal decision making not entailing an overt action. It was further considered that while the length of the cycle was fixed, the processing rate per decision might be variable, permitting changes in the total bit per second processing rate of the individual. This would imply that the presentation of more information than the system could process would result

in 1) some of the information being ignored, 2) the information being incompletely processed (errors) or 3) the system would increase its speed to accommodate the information. These possibilities agree with those mentioned by Fitts and Posner (1967) when describing Miller's overload studies. Karlin and Keslerbaum (1968), in research on the psychological refractory period tended to verify the existence of a "necessary central delay time for the resolution of event uncertainty" which might correspond to the effect of the real time responses required for internal processes. The increase in the first response time, not explained by their work, might be explained by the central processor watching for the second input while processing the first. Work by Schaffer (1968) tends to support this. When serial dependencies were introduced, the tendencies for the plots of response latencies to cross was reduced, indicating the central processor was able to predict the second with enough accuracy to reduce its response time.

Sjoberg (1968) described an inverted U-shaped efficiency curve, where efficiency first increased then decreased as a function of arousal. He stated that one of the most reliable measures of arousal was the heart rate. A change in heart rate would indicate an increase in internal processing at the extremes, where close control was necessary. For ranges of heart rate normally encountered, the control cycle might adjust speed without increasing actual processing, permitting additional external processing. For unusual ranges, extra

processing would be required for internal processing, reducing the amount available externally. In this context, the U-shaped efficiency curve applies to the model. If in fact, external processing can increase arousal, then any ability test based on a manifestation of the internal cycle would in fact be measuring how readily and/or how much along the curve an individual moves with increasing external processing.

Works similar to those of Brenner and Hothersall (1971) and Engel and Hanson (1971) are significant in that they show autonomous characteristics such as heart rate and blood pressure can be controlled by the individual. Additionally, control was best when feedback via visual or audible signals was provided, indicating that decisions concerning their activities were normally controlled by the same part of the brain that is modeled as making conscious decisions. In particular, the effect of an audible timing signal on smoothing the respiration irregularity mentioned earlier both confirms the inclusion of respiration decisions as real time components of the control cycle, and the time sharing aspects of the hypothesis. When the brain had a signal it could use to time respiration, the processing required was reduced, permitting better control of respiration amplitude. Laverne and Engle (1971) mentioned an instance when an individual was able to control both heart rate and arrythmia rhythm. This implies a person can learn to speed his control cycle too if needed. Their surprise at this phenomena underlined the lack of work in the area.

III. EXPERIMENTAL PROCEDURE

A. EXPERIMENTAL DESIGN

The experiment was structured as a set of three mental load conditions corresponding to one, two, and three bit serial reaction time tests, with each subject being tested at one of three inter-task times. A task was defined as the subject's actions from the initiation of a stimulus until the correct completion of the response, and the inter-task time as the time from completion of the last response until initiation of the stimulus of the next task. Of a total of 45 subjects, six were tested at an inter-task time of .1 seconds, nine were tested with one of .5 seconds, and thirty with one of 1.0 seconds. This provided a graded set of mental stress conditions, over both complexity and presentation rate. The outputs were the total number of tasks and the total response time for each of the three complexities, and the ECG with cardiotachometer plot taken throughout testing, for each subject. All subjects were new students in the Masters degree program in Operations Research at the Naval Postgraduate School. After three quarters of instruction, the cumulative grades for each quarter for each subject were obtained from his academic record. It was felt that using the first quarter grades as an indication of the subject's initial knowledge, the trends in grade would be indicative of his relative ability to master new information as the program

progressed. The third quarter cut off was arbitrary and was selected primarily to permit a timely completion of the study.

B. CONDUCT OF THE EXPERIMENT

Each subject was first asked to fill out a questionnaire. (See Fig. 2) He was then wired for an ECG (See Fig. 3), instructed on the test, then given a one minute relaxation period. The actual tests were each two minutes in length, each followed by a one minute rest. For the first test, one of two lights would be lit, and remain on until the subject pushed the appropriate button with his left or right fore-finger. After the light was turned off, there would be a short inter-task period, after which a light would again come on. The number of tasks completed, and the total response time were recorded automatically. The next two tests were identical, except for the number of lights from which the one to be lit was selected. For the second test there were four, and the third eight. In all cases, the lights were selected mechanically in a nonrepeating random manner, with equal probabilities of selection. The inter-task time was a constant for each group of subjects.

Additional information was collected from each student by means of the questionnaire filled out by the student prior to the test. The remainder of the data was composed of an ECG with cardiotachometer plot, and the response data taken during testing.

NAME________________________________ AGE________________

SERVICE___________________ UNDERGRADUATE SCHOOL__________

HAVE YOU TAKEN THE GRE APTITUDE TEST? YES_____ NO _____

DID YOU REQUEST THE O. A. CURRICULUM? YES______ NO______

DO YOU SMOKE? YES_______ NO______

ARE YOU UNDER MEDICATION? YES______ NO______

HAVE YOU PARTICIPATED IN ANY PHYSICAL ACTIVITY IN THE LAST 1 HOUR? YES______ NO______

DO YOU HAVE ANY EMOTIONAL/MENTAL STRAINS? YES______ NO ______

HOW WOULD YOU RATE YOUR CONCENTRATION ABILITY?
EXCEPTIONAL______ ABOVE AVE______ AVE______ BELOW AVE__

HOW DO YOU RATE YOUR ABILITY TO ANALYZE A COMPLEX SITUATION OR PROBLEM?
EXCEPTIONAL_____ ABOVE AVE_____ AVE_____ BELOW AVE_____

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

REST	BPM_____	SA_____			
1 BIT	BPM_____	SA_____	# TASKS_____	TIME_____	RATE_____
	BPM_____	SA_____	# TASKS_____	TIME_____	RATE_____
2 BIT	BPM_____	SA_____	# TASKS_____	TIME_____	RATE_____
	BPM_____	SA_____	# TASKS_____	TIME_____	RATE_____
3 BIT	BPM_____	SA_____	# TASKS_____	TIME_____	RATE_____
	BPM_____	SA_____	# TASKS_____	TIME_____	RATE_____

Figure 2. Sample Questionnaire

Figure 3A. Equipment

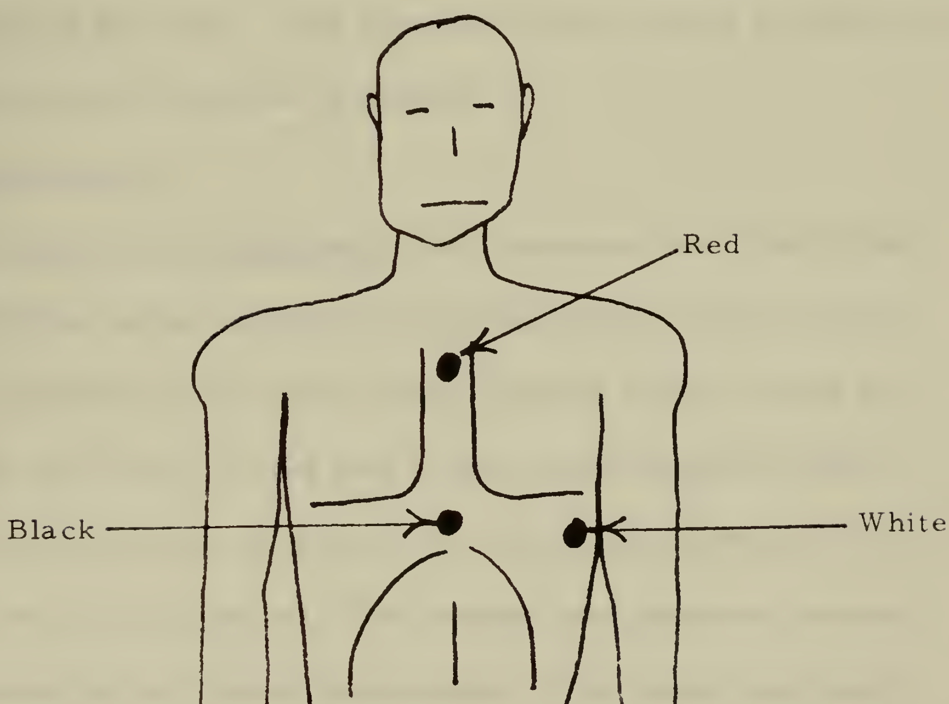

Figure 3B. Electrode Placement

C. APPARATUS

The mechanical apparatus used to collect the information was composed of two major assemblies, a Beckman four pen recorder, and a Lehigh Valley Electronics Human Test Equipment assembly. (See Fig. 3)

1. Heart Measurements

The Beckman recorder was used to plot the ECG and the cardiotachometer output. A connection to the Human Test Equipment assembly marked the chart automatically when each test started and stopped. The cardiotachometer plot was calibrated to a 1.5 cm. deflection each direction to show a total velocity change from 60 to 120 BPM. The ECG plot was not calibrated, but adjusted to show the complete pulse of the heart. The electrodes were placed as shown on Figure 3. The chart speed was 2 mm/sec.

2. Test Control

The Human Test Equipment was composed of a 3X4 display of lights, with the center column taped to reduce the visible number to eight and numbered from one to eight, starting at the top left and moving right, then down, a 3X4 push button array similarly taped, and an electromechanical relay board to operate the lights and buttons. The buttons were not numbered. The subject was required to select the proper button by its spatial relationship. The board was wired to operate 2, 4, or 8 lights during any test to control the complexity of the test. Three pulse emitters set to .1, .5, and 1.0 sec between

pulses were used to generate inter-task times. The emitters were selected by switch to eliminate resetting errors. The lights were turned on in a nonrepeating random sequence. The device used to introduce randomness also introduced temporal uncertainty as well as the desired choice uncertainty by varying the actual inter-task time about the chosen mean value. As each light was turned on, the response timer was started. When the correct button was pushed by the subject, the response timer was stopped, and the task counter advanced one unit. At the end of the test, the number of completed tasks and the total response time were copied onto the questionnaire, and the clock and the counter set to zero. The test timer was set to two minutes and not varied.

3. Limitations

The system emitted an audible click. Each subject was required to wear a headset with white noise (static), however it is possible that some were able to hear the click above the noise. Inadequate facilities prevented taking respiration traces, and necessitated the acceptance of temporal uncertainty where only choice uncertainty was desired. Provision could not be made for errors in response, as a result of which individual data points include the response time to correct these errors. An attempt was made to account for motivation in the testing by offering a selected group a reward of $10.00 to the subject with the fastest average response time.

An unpublished analysis performed by Bacon, et al (1972) failed to show any significant difference between this group and the remainder.

IV. ANALYSIS OF DATA

A. THE SINUS ARRYTHMIA MEASURES

Since the model was designed to show the relationship of an internal control cycle to external information processing, the frequency of sinus arrythmia change was selected as the applicable measure. The suppression of sinus arrythmia with mental loading posed a critical problem in establishing the frequency of the irregularity, in that with extreme loadings, the sinus arrythmia curve approximated a straight line. An analysis of the ECG plot produced a suitable concurrent frequency in the height of the ECG plot. (See Fig. 4) This curve closely approximated the sinus arrythmia curve in all respects except suppression. Like sinus arrythmia, the curve could be modified by respiration changes. The number of changes was determined by counting the peaks in the ECG curve between the end points plotted by the Beckman recorder, then counting again in the other direction to insure a correct count. (See Fig. 4) This number was divided by the applicable time period in seconds to produce the control cycle speed.

For the 1.0 second inter-task time group, a second measure of sinus arrythmia was used. The area enclosed by the electrocardiogram rate curve, and the mean heart rate line drawn through it was computed for 28 of the group's data points by Douglas (1972). The

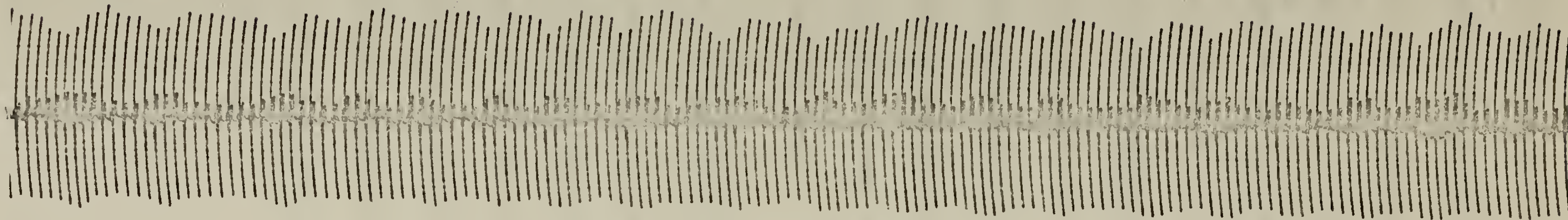

Figure 4A. ECG Showing Cyclic Pattern Used to Compute Control Cycle Speed

Figure 4B. Cardiotachometer Output Showing Sinus Arrythmia

works of Kalsbeck (1971) and Hicks and Soliday (1972) showed sinus arrythmia suppression to be related to mental load. The area under the curve was selected as a measure since this data was available from work done by Douglas using the same subjects. Both measures were treated as raw numbers and as trends from rest (the ratio of the load measure to the rest measure. The ratio of area under load to area while resting was called the area suppression measure). The area suppression measure was also tested as being an addition to an available processing capability, rather than a measure of the total available capability by itself. This was accomplished by subtracting the ratio of the area under load over the area at rest from the number two, five, or ten.

B. THE BEHAVIOR OF THE MEASURES WITH MENTAL LOAD

A computer correlation routine was used to compute means, standard deviations, analyses of variance, and correlations for functions of the measures, and functions of the mental load. The mean control cycle speed at rest for each group was compared with the mean control cycle speed for the same group under load, using the student's t test. For all three groups the change in frequency was significant at the .0005 level.

TABLE I

Effect of Information Processing on Internal Control Cycle Speed Multiplied by 120 Seconds

Inter-task Time	# of Subjects	Mean Rest Speed	Speed Under Load	t	p
.1	6	35.8	49.5	4.17	.0005
.5	9	37.5	44.07	3.06	.0005
1.0	30	37.9	44.19	3.05	.0005

The mean control cycle speeds at rest were compared between groups using analysis of variance. No significant differences were noted.

TABLE II

Comparison of Control Cycle Speeds At Rest

Source	SS	df	ms	F	p
Total	2184.8	44	-	-	-
Between groups	21.95	2	10.97	.21	ns
Within groups	2162.89	42	51.5	-	-

The mean control cycle speeds under load for each group and complexity were tested with a two way analysis of variance with repeated measures on one factor. There were significant differences between groups. The control cycle speeds were tested as ratios of the values under load to the rest value (percentage of the rest value).

TABLE III

Comparison of Control Cycle Speeds Under Load

Source	SS	df	ms	F	p
Total	42.2	134	-	-	-
Between Subjects	41.2	44	-	-	-
Presentation rate (R)	21.8	2	10.9	23.6	.001
Error B	19.4	42	.46	-	-
Within Subjects	.99	90	-	-	-
Complexity (C)	.008	2	.004	.34	ns
RXC	.05	4	.013	1.1	ns
Error W	.93	84	.01	-	-

When the tasks completed and the response times were tested, it was found that both varied significantly with both increasing complexity and decreasing inter-task time.

TABLE IV

Comparison of Number of Tasks Completed for Each Loading

Source	SS	df	ms	F	p
Total	200,447	134	-	-	-
Between Subjects	189,940	44	-	-	-
Presentation rate (R)	185,978	2	92,989	985.7	.001
Error B	3,962	42	94.3	-	-

TABLE IV (continued)

Source	SS	df	ms	F	p
Within Subjects	10,507	90	-	-	-
Complexity (C)	2,617	2	1308	31.4	.001
RXC	4,387	4	1096	26.3	.001
Error W	3,502	84	41.7	-	-

TABLE V

Comparison of Total Response Times for Each Loading

Source	SS	df	ms	F	p
Total	78,264	134	-	-	-
Between Subjects	74,609	44	-	-	-
Presentation rate (R)	71,670	2	35,835	512.2	.001
Error B	2,938	42	69.96	-	-
Within Subjects	3,655	90	-	-	-
Complexity (C)	1174	2	587.0	21.1	.001
RXC	143.6	4	35.9	1.3	ns
Error W	2338	84	27.8	-	-

The test performed on the information processing rates in tasks per second found significant differences with increasing complexity, but not with decreasing inter-task times.

TABLE VI

Comparison of Processing Rates in Tasks per Second Response

Source	SS	df	ms	F	p
Total	8.69	134	-	-	-
Between Subjects	2.55	44	-	-	-
Presentation rate (R)	.12	2	.059	1.01	ns
Error B	2.44	42	.058	-	-
Within Subjects	6.13	90	-	-	-
Complexity (C)	3.47	2	1.73	55.7	.001
RXC	.048	4	.012	.38	ns
Error W	2.62	84	.031	-	-

The means behaved in an unexpected manner. The means of the control cycle speed under load for the 1.0 and .5 second groups were comparable, while those for the .1 second group were higher. An examination of the corresponding information processing rates in tasks per second of response showed just the reverse effect - the average processing rates for the 1. and .1 second groups were virtually identical, while those of the .5 second group were somewhat lower.

When the ratios of tasks per second response divided by control cycle speed were tested significant differences were found both with increased complexity and decreasing inter-task time.

TABLE VII

Comparison of Processing Rates Divided by Control Cycle Speeds

Source	SS	df	ms	F	p
Total	15.56	134	-	-	-
Between Subjects	12.48	44	-	-	-
Presentation rate (R)	5.69	2	2.84	17.6	.001
Error B	6.79	42	.16	-	-
Within Subjects	3.08	90	-	-	-
Complexity (C)	1.35	2	.67	33.1	.001
RXC	.027	4	.0068	.33	ns
Error W	1.70	84	.02	-	-

This effect is best illustrated by comparing graphs of the information processing rates for each group, with a graph where the information processing rates are normalized by the appropriate control cycle speeds to eliminate that variable. The plots become more linear, become ordered by inter-task time, and take on a spacing on the order of the differences in inter-task time. (See Fig. 5) This effect of increasing complexity and presentation rate is intuitive, but was not expected from the data.

Four measures of mental load were used: 1.) tasks per test (mean stimulus rate, in tasks per second of test) 2.) tasks per second

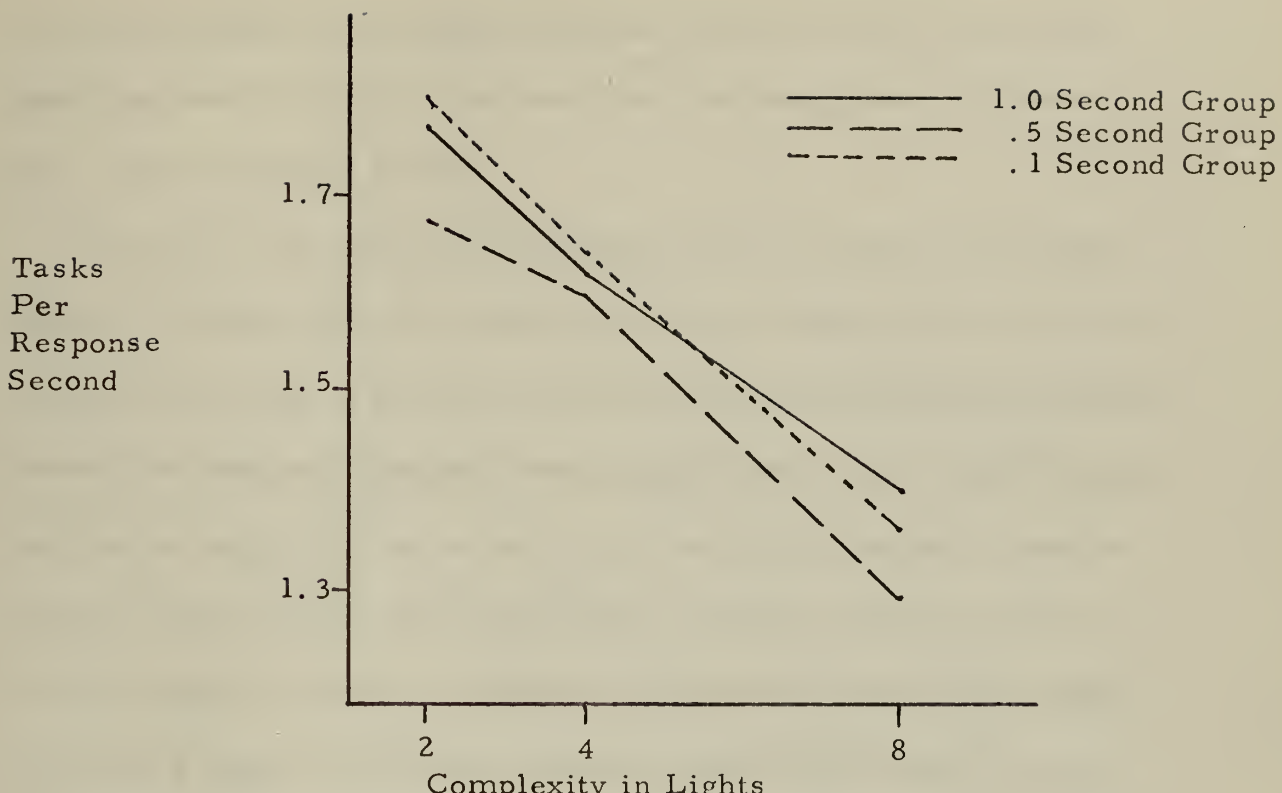

Figure 5A. Mean Information Processing Rates

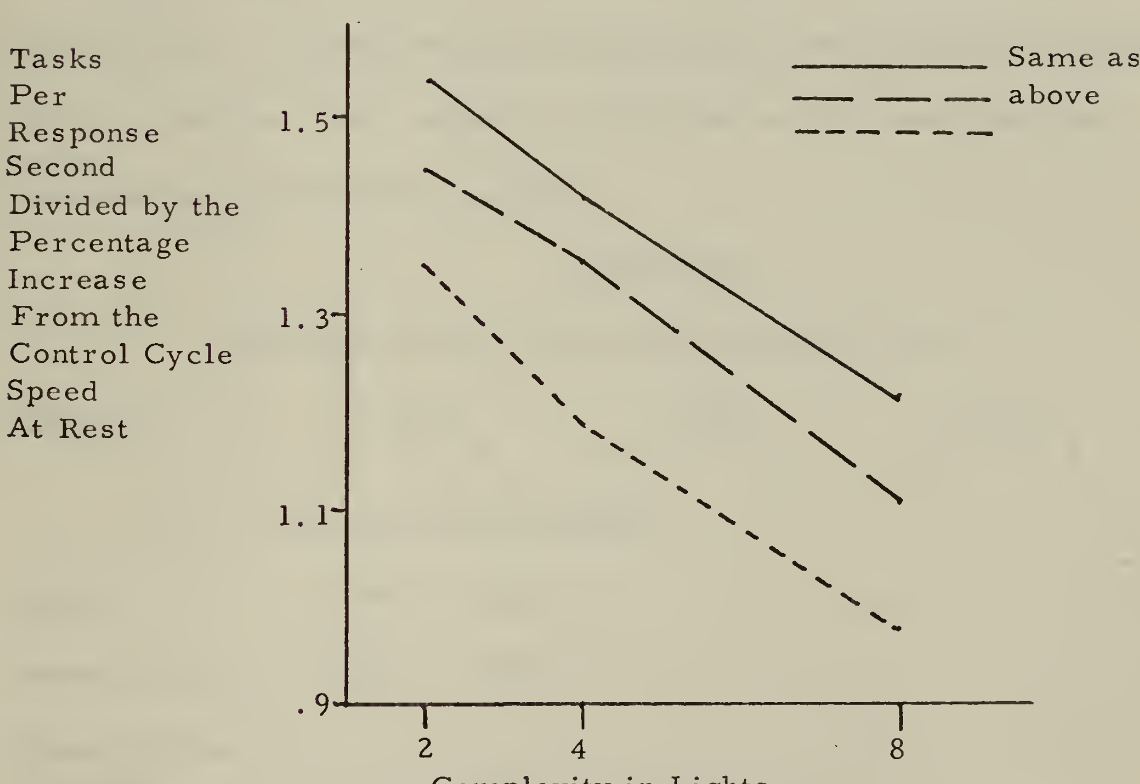

Figure 5B. Normalized Mean Information Processing Rates

of response time, 3.) response time per test (per cent of test time spent responding) and 4.) response time per task (mean response time - the reciprocal of #2).

For the .1 second inter-task time group, the rest control cycle speed correlated with the loaded control cycle speed at the four light complexity (p=.05). For the 1.0 second group, the same correlations for the two and four light tests were significant at the p= .0005 level, and for the eight light test at p= .005. For all presentation rates a function of the number of tasks per test, response time per test, or a ratio of the two combined with the appropriate control cycle speed produced a higher correlation with the control cycle speed at rest than cycles under load alone. It was noted that the significant correlations for the .5 second inter-task time group were obtained by computing the trend from one complexity to the next of the same functions used directly for the other groups.

TABLE VIII

Correlations with Control Cycle Speed at Rest

Function	2 light		4 light		8 light	
	r	*p*	*r*	*p*	*r*	*p*
a. .1 Second Inter-task Time						
Cycles	.795	.05				
Time X Cycles	.872	.025				
Tasks X Time X Cycles	.714	ns	.751	.05		

TABLE VIII (continued)

Function	2 light r	2 light p	4 light r	4 light p	8 light r	8 light p
b. .5 Second Inter-task Time						
Cycle Trend	-.819	.005	-.629	.05		
Time X Cycle Trend	-.788	.01	-.816	.005	-.683	.025
Tasks X Cycle X Time Trend	-.825	.005	-.659	.05	-.518	ns
c. 1.0 Second Inter-task Time						
Cycles	.552	.005	.662	.0005	.512	.005
Tasks/Cycle	-.485	.005	-.742	.0005	-.484	.005
Tasks X Cycle	.564	.005	.642	.0005	.513	.005

The area suppression data was not available for the .1 and .5 second inter-task time groups. For the .1 second inter-task time groups, the control cycle speed correlated (r=.737, p=.05) with the number of tasks in the test at the eight light complexity. Further, the trend in control cycle speed as the complexity increased from two to four lights correlated (r=.745, p=.05) with the trend in response time per test as the complexity increased from two to eight lights. For the .5 second group, the trend in control cycle speed as complexity increased from four to eight lights correlated (r=.736, p=.025) with the trend in information processing, in tasks per second of response time, as the complexity of task increased from two to eight lights.

For the 1.0 second group, where area suppression data was available, it was found that the control cycle speed and suppression data combined produced the best results. For each of the four mental load measures, the cycle rate under load at one of the complexities correlated significantly (p=.05 to p=.005) with the mental load measure modified by the area suppression measure. In all cases this correlation exceeded that between any two of the measures taken together.

TABLE IX

Increase in Correlations Between Control Cycle Speed and Mental Load

Mental Load Function	Correlation With Control Cycle Speed r	p	Mental Load Multiplied by	New Correlation With Control Cycle Speed r	p
Response Time	.132	ns	$\frac{\text{A Load}}{\text{A Rest}}$	.464	.01
Tasks	.397	.025	$2 - \frac{\text{A Load}}{\text{A Rest}}$	.470	.01
Tasks per Response sec.	-.220	ns	$\frac{\text{A Load}}{\text{A Rest}}$	-.447	.01

C. SCHOLASTIC ACHIEVEMENT PREDICTION

The grades for each subject for the first three quarters of the Operations Research Masters degree program were used as the indicators of scholastic achievement. Correlations were computed for the individual quarters, as were correlations for the trends in

grades from the first to the second, the first to the third, and the second to third. The trend in response time per test from one complexity to a higher one proved to be the most consistent (and best) predictor of trend for the .1 and 1.0 second inter-task time groups, while the .5 second group the best predictor was the trend with increasing complexity of the product of the control cycle speed under load and the mental load in tasks per response second. Inclusion of area suppression in the correlations with grade trend for the 1.0 second group could not improve upon the correlation already achieved.

TABLE X

Grade Trend Correlations

Group	Quarters	Complexity	r	p
a. Trend in Response Time				
.1 sec	1 to 2	4 to 8	.736	.05
	2 to 3	4 to 8	.882	.01
	1 to 3	4 to 8	.938	.005
1.0 sec	1 to 3	2 to 8	.707	.0005
	2 to 3	2 to 4	.533	.005
b. Trend in Control Cycle Speed X Tasks/Second Response				
.5 sec	2 to 3	2 to 4	.862	.005

The most consistent predictor (and best) of individuals grades was the mental load as a product of the tasks completed and the response time for the 1.0 and .1 second groups (p=.01, .005). For

the .5 second group the best (there was no consistent predictor) was the product of the control cycle speed under load, the number of tasks completed, and the response time. Inclusion of area suppression produced a higher correlation between response seconds per task and grades for the third quarter for the 1.0 second group.

TABLE XI

Grade Correlations

Group	Quarters	Complexities	r	p
a. Trend in Tasks Per Test X Response Time				
.1	1	2 to 8	.752	.05
	2	2 to 8	.818	.025
	3	2 to 8	.906	.01
	1	4 to 8	.864	.025
	2	4 to 8	.772	.05
	3	4 to 8	.783	.05
1.0	1	2 to 8	.334	.05
	2	2 to 8	.489	.005
b. Control Cycle Speed X Tasks X Response Time				
.5	3	2	.621	.05
c. Response Seconds/Task X (2- A load/A rest)				
1.0	3	8	-.498	.005

V. DISCUSSION AND CONCLUSIONS

The trend noted when comparing control cycle speed and information processing rates with decreasing inter-task time indicates that up to a point, the response to decreasing inter-task time is an increase in response time. After that point, the response is to speed the internal cycle and bring the response time back down toward the individual's best. This point appears to be between .5 and .1 seconds inter-task time. This phenomena may relate directly to the differing results in the previously mentioned psychological refractory period studies. With the short inter-task times, the stimuli are appearing at a more predictable rate, and the brain can more easily adjust its scheduling to process them. This agrees with the findings when serial dependencies were introduced in Shaffer's (1968) study.

The significance of the correlations between the cycles rate, ar· a suppression, and information processing lies in the refinement of the ability to gauge mental load from physiological factors. The relationships are yet very crudely defined, however, it appears that with additional control, an accurate estimate of the complexity and density of information processing can be made. An examination of the individual data points shows several subjects with an inordinately large response time for one test (as compared with their performance on the more complex tests). This would indicate that the lack of control over

errors influenced the results with respect to those points. Eliminating these points resulted in a consistent progression from one complexity to the next of response seconds per task multiplied by the scaled control cycle speed and area suppression factors. Even without eliminating those points, the progression is more consistent than the unmodified response seconds per task data. The products vary differently from individual to individual. In fact, the trend from the two-light complexity to the eight-light complexity of this product correlates highly with grade trend from first to third quarter. ($r = .651$, $p = .0005$) for the 1.0 second group.

The correlations with grades and grade trends is high primarily due to the difficulty of the material taught. The courses are graded "on a curve", and it is intuitive that the most capable individuals would tend toward the top of the class. Some problems involved with grades as a measure of scholastic performance are the limitations on maximum and minimum grade - an individual at the top or bottom cannot progress further, causing an outlier. Furthermore, individual students have course preferences, and will do better or worse than expected depending on the course and instructor. With these considerations a more realistic measure of performance was desired, but was not available.

The control cycle speed appears to be a useful predictor of an individual's response rate, given the stimulus rate and the individual's rest and test condition cycle rates. In conjunction with the area

suppression measure, the same data can be used to estimate an individual's total mental load. With additional control and refinement it is believed that these measures can further be used to estimate an individual's potential for scholastic achievement with respect to his contemporaries. It is not felt that the measures are of sufficient accuracy to permit this at present, but it is expected that further work will provide a sufficiently accurate tool for this purpose.

APPENDIX
TEST DATA

CONTROL CYCLES PER TEST

SUBJECT	REST	2 LIGHTS	4 LIGHTS	8 LIGHTS
	A. .1 SECOND GROUP			
1	21.00	44.50	46.00	49.50
2	43.00	56.50	59.50	57.00
3	15.00	38.00	45.30	48.00
4	20.00	58.00	55.00	54.00
5	17.00	42.00	42.00	41.50
6	23.00	53.00	51.00	50.00
	B. .5 SECOND GROUP			
7	19.00	37.00	42.00	37.50
8	22.00	44.00	41.00	42.00
9	20.00	41.50	42.00	42.80
10	16.00	37.00	35.00	35.00
11	24.00	48.00	49.00	47.00
12	22.00	41.50	47.50	47.30
13	15.00	48.00	50.00	46.50
14	20.00	48.00	49.00	50.50
15	16.00	47.00	45.50	48.00
	C. 1. SECOND GROUP			
16	20.00	30.30	34.00	31.00
17	36.00	49.50	43.50	47.00
18	26.00	39.50	44.00	45.00
19	38.50	49.00	54.00	56.30
20	28.00	31.00	33.50	39.30
21	40.00	58.00	46.00	39.00
22	37.50	43.00	43.50	43.50
23	25.00	49.00	48.00	48.30
24	35.50	46.50	46.60	47.50
25	37.50	55.00	53.50	54.50
26	26.50	36.00	31.50	30.50
27	27.00	35.50	33.00	35.50
28	23.00	62.00	54.00	58.00
29	38.00	43.50	47.00	47.00
30	30.50	39.50	39.50	40.00
31	37.00	51.50	48.80	47.00
32	34.00	46.00	48.50	46.50
33	36.00	55.00	54.50	55.00
34	40.00	60.00	53.00	54.50
35	40.50	47.00	48.50	53.00
36	26.00	34.50	32.50	35.50
37	19.00	41.30	41.00	41.00
38	37.50	47.50	51.50	45.50
39	20.00	37.00	37.00	39.00
40	31.50	43.50	43.50	47.00
41	26.00	36.00	35.50	38.00
42	19.00	31.00	32.50	30.50
43	41.50	41.50	43.00	38.50
44	21.50	47.50	38.50	46.00
45	33.00	50.80	48.00	49.50

INFORMATION PROCESSING DATA

SUB JECT	2 LIGHTS TASKS	TIME	4 LIGHTS TASKS	TIME	8 LIGHTS TASKS	TIME
	A. .1 SECOND GROUP					
1	184.00	117.50	196.00	118.00	158.00	118.30
2	205.00	101.40	194.00	113.80	163.00	111.80
3	200.00	101.20	190.00	111.40	159.00	118.50
4	201.00	104.60	193.00	107.60	174.00	105.90
5	200.00	112.50	177.00	113.90	134.00	110.50
6	169.00	109.30	157.00	109.90	138.00	116.60
	B. .5 SECOND GROUP					
7	95.00	53.70	95.00	64.10	79.00	65.40
8	98.00	56.40	82.00	48.30	69.00	54.30
9	89.00	52.90	80.00	54.70	72.00	54.70
10	92.00	52.10	103.00	57.70	77.00	55.10
11	94.00	55.30	105.00	60.60	80.00	64.60
12	90.00	59.60	95.00	69.00	84.00	68.40
13	107.00	62.90	94.00	53.90	58.00	44.60
14	93.00	52.30	101.00	59.40	84.00	55.90
15	101.00	69.60	97.00	65.60	91.00	77.50
	C. 1. SECOND GROUP					
16	62.00	30.30	67.00	47.30	67.00	48.30
17	60.00	29.70	62.00	36.30	60.00	37.60
18	63.00	37.60	71.00	42.10	63.00	42.90
19	67.00	33.20	66.00	41.20	69.00	57.30
20	58.00	36.50	68.00	47.80	59.00	42.50
21	69.00	33.20	60.00	43.30	69.00	53.50
22	62.00	32.20	66.00	39.80	62.00	44.20
23	55.00	37.70	79.00	45.60	66.00	51.40
24	69.00	34.60	67.00	31.40	65.00	46.50
25	69.00	44.50	75.00	52.20	65.00	46.50
26	69.00	36.00	64.00	38.80	63.00	36.60
27	70.00	37.00	61.00	34.10	59.00	39.00
28	64.00	36.60	71.00	40.60	58.00	43.60
29	69.00	39.30	62.00	40.30	68.00	49.30
30	69.00	39.20	68.00	42.80	78.00	52.50
31	77.00	45.50	71.00	49.90	69.00	47.70
32	64.00	22.50	75.00	49.40	58.00	43.80
33	68.00	49.30	64.00	36.20	65.00	39.10
34	65.00	34.20	71.00	49.90	68.00	52.70
35	72.00	40.70	48.00	26.20	63.00	44.90
36	71.00	41.80	62.00	32.80	66.00	48.80
37	66.00	37.20	69.00	43.30	61.00	43.80
38	78.00	43.60	76.00	44.10	61.00	41.80
39	75.00	43.70	70.00	48.60	70.00	52.10
40	51.00	38.50	69.00	45.70	64.00	53.20
41	65.00	33.00	66.00	33.80	66.00	45.30
42	61.00	37.70	69.00	43.60	67.00	45.60
43	63.00	43.10	69.00	41.00	63.00	47.30
44	65.00	36.60	64.00	39.70	70.00	52.40
45	65.00	55.60	70.00	62.30	67.00	54.80

AREA SUPPRESSION DATA

1.0 SECOND GROUP

SUBJECT	REST	2 LIGHTS	4 LIGHTS	8 LIGHTS
18	426.00	205.00	177.00	126.00
19	297.00	206.00	326.00	196.00
20	285.00	127.00	169.00	117.00
21	267.00	115.00	203.00	167.00
22	370.00	211.00	147.00	213.00
23	197.00	130.00	123.00	89.00
24	541.00	197.00	133.00	166.00
25	456.00	106.00	138.00	155.00
26	351.00	210.00	245.00	192.00
27	319.00	202.00	175.00	152.00
28	330.00	223.00	144.00	143.00
29	160.00	135.00	167.00	190.00
30	299.00	317.00	243.00	340.00
31	282.00	165.00	159.00	265.00
32	34.00	32.00	27.00	20.00
33	185.00	69.00	73.00	88.00
34	134.00	137.00	112.00	135.00
35	321.00	149.00	64.00	113.00
36	457.00	223.00	219.00	239.00
37	271.00	163.00	119.00	147.00
38	308.00	155.00	389.00	207.00
39	393.00	243.00	217.00	156.00
40	274.00	142.00	108.00	174.00
41	354.00	317.00	218.00	153.00
42	460.00	329.00	335.00	226.00
43	191.00	307.00	174.00	191.00
44	323.00	170.00	202.00	151.00
45	213.00	127.00	153.00	100.00

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ABSTRACT

Three groups of subjects were tested with serial reaction time tests of varying complexity and presentation rate. An ECG was collected from each subject throughout the test, and a measure of internal processing speed was defined using the ECG as input. It was found that there was an observable effect of the internal processing speed on the response rate of the subjects. An examination of relative scholastic achievement of the subjects showed that it was related to the change in the subject's performance as the complexity of the serial reaction time test was increased.

KEY WORDS	LINK A		LINK B		LINK C	
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